Acute medical unit design

Bokhorst, Jos A.C.; van der Vaart, Taco

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Acute Medical Unit design – the impact of rearranged patient flows

Jos A.C. Bokhorst*

Department of Operations, Faculty of Economics and Business, University of Groningen, Nettelbosje 2, 9747 AE Groningen, The Netherlands,
j.a.c.bokhorst@rug.nl +31 50 3634693

Taco van der Vaart

Department of Operations, Faculty of Economics and Business, University of Groningen, Nettelbosje 2, 9747 AE Groningen, The Netherlands,
j.t.van.der.vaart@rug.nl +31 50 3637060

Acute Medical Units (AMUs) are instigated in many hospitals across the world. An AMU admits acute patients, mainly arriving via the emergency department, for further assessment, care and treatment for a maximum designated period. Thereafter, patients who require additional care are transferred to regular wards that also admit elective patients. The literature reports several benefits (including reductions in in-patient mortality and in the length of stay), with these conclusions mostly based on empirical findings from studies focused on acute patient performance only. This paper sheds light on the potential hospital-wide impact of implementing a range of AMU designs in terms of length of the designated period, size and transfer policy. A simulation study is performed based on data from a large Dutch hospital. When establishing an AMU, hospitals usually transfer resources from existing wards to the new AMU. This seems logical since these wards receive fewer acute admissions once an AMU is in place. However, our research shows that this transfer of resources decreases the overall performance (of the AMU and the wards) for all the AMU designs investigated. We report on the scale of these negative effects and the required reduction in the length of acute patients' stays required to compensate for these effects.

Keywords: Acute Medical Unit; Simulation; Healthcare; Patient flows

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* Corresponding author.

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1 Introduction

Hospitals have been restructuring their acute patient flows to overcome problems such as Emergency Department (ED) overcrowding, fragmented treatment of acute admissions and the resulting negative medical consequences. In the United Kingdom, the establishment of a target that 95% of patients should spend no more than four hours in ED before discharge or an intra-hospital transfer triggered the introduction of the acute medical unit (AMU). AMUs were established to admit acute patients for a designated period for expedited multidisciplinary and medical specialist assessment, care and treatment. This concept rapidly took hold in both the UK and Australia (Scott, Vaughan and Bell 2009) and it is gaining in popularity in other countries around the world.

Several studies have reviewed the effectiveness of AMUs in hospitals (Scott, Vaughan and Bell 2009; Byrne and Silke 2011; Reid et al. 2016). Reported benefits are an improved patient outflow from the ED, a reduced average length of stay (LOS) in the hospital, increased direct discharge rates (patients sent home) within a fixed number of hours from arrival at the ED (24h, 48h), no increase in readmission rates, reduced in-patient mortality plus greater patient and staff satisfaction (Jayawarna et al. 2010; Moloney et al. 2005; Moloney, Bennet and Silke 2007; Rooney et al. 2008; Scott, Vaughan and Bell 2009). However, most of these results are obtained from empirical studies in which retrospective before–after analyses of a single case are described. Further, the publications do not usually elaborate on the precise configuration or design of the AMU in their specific case. Therefore, it remains unclear how the design of an AMU affects performance. Moreover, these studies tend to focus on acute patient outcomes only. The efficiency/cost advantages of implementing an AMU have largely been attributed to a reduced length of stay of acute patients leading to less bed-days (Moloney, Bennet and Silke 2007; Scott, Vaughan and Bell 2009). However, we argue that the presence of an AMU may also affect elective patient flows. To create an AMU, hospitals generally shift existing capacity (beds and staff) from existing wards to the new AMU. In advance, it is uncertain how acute and elective patient outcomes will be affected by pooling acute patients for a designated period while also temporarily separating acute and elective flows through instigating an AMU. As such, our main contribution is to study the impact of AMU design on hospital-wide performance.

In this study, we will specifically investigate three AMU design aspects (the period designated for acute patients to stay in the AMU, the size of the AMU and the transfer policy) to evaluate their effects on the resulting rearranged patient flows. The designated period for acute patients to stay in the AMU obviously influences the required size of the AMU in terms of the number of beds. The longer the designated period, the more beds will be required in the AMU to be able to handle all the arriving acute patients. A longer period may have benefits (economies of scale and acute patients less likely to need to transfer to a ward after admission to the AMU), but these AMU beds are no longer available elsewhere in the hospital for elective patients. Consequently, this could worsen elective patient flows, especially if the number of patients needing to transfer to a ward does not decrease significantly and/or the variability in elective patient arrivals is such that the smaller wards cannot cope. The policies designed for intra-hospital patient transfer are likely to influence the capacities available at various times for acute and elective patients. As such, transfer policies will impact on the hospital-wide performance and may also interact with the specific choice of AMU design.

To study the hospital-wide effects of these aspects of AMU design, we use a Discrete Event Simulation (DES) approach. DES is widely used for performance modelling in healthcare (Brailsford et al. 2009; Günal and Pidd 2010; Mielczarek 2016). In healthcare, DES is particularly applied in the domain of healthcare system operations and improvements when focusing on supporting decisions regarding staff scheduling, appointment systems, resource allocation and the planning of auxiliary services (Mielczarek 2016). While such simulation models tend to focus on specific parts/units of a hospital (such as operating theatres, emergency departments or inpatient facilities), the suggestion has been made that future research should address holistic hospital-wide issues (Günal and Pidd 2010). In response, our study falls within the domain of healthcare system operations and improvements, and considers the impact of rearranged patient flows involving multiple healthcare units (AMUs and wards).

Compared to the empirical approach used in earlier studies to assess the effectiveness of AMUs, the DES approach has several important benefits. First, it enables one to explore AMU designs without disrupting ongoing hospital operations, and without substantial investments. It allows “what if” testing by exploring different model settings. Furthermore, by adopting this approach, we were able to compare a realistic model of a specific hospital without an AMU (the existing situation) with several alternative AMU designs while controlling the conditions under which the experiments were performed. Events that are hard to control in real-life, such as the arrival pattern of patients, can be repeatedly simulated with DES and applied to different AMU configurations. Other real-life influences, such as changes in regulations and learning effects on employees, can be consistently modelled in all the experiments. This makes direct comparisons between alternatives possible.

The paper is structured as follows. First, Section 2 reviews the literature relating to Acute Medical Units. Section 3 presents our Dutch hospital case and sheds light on the aims of its decision-makers and the design aspects considered. Section 4 describes the simulation model and the experimental design to examine an appropriate AMU design and the resulting effects on hospital-wide performance. Following this, Section 5 presents the results, which are then discussed in Section 6. Finally, Section 7 draws conclusions.

2 Literature review

2.1 The Acute Medical Unit (AMU) concept

Traditionally, acute patients who needed to be admitted after visiting the ED (i.e. acute admissions) have been directly admitted to various wards irrespective of the time of day. Each ward would generally be related to one or more medical specialties, and most of their admissions would be elective patients (patients who were scheduled in advance). Nighttime emergency admissions would then disturb elective patients, block access and result in ED overcrowding if too few beds were available in the relevant wards. It also led to a longer than necessary length of stay due to the fragmented care of acute patients, and limited the means and equipment available to medical specialists to rapidly assess acute admissions (Cooke, Higgins and Kidd 2003; Scott, Vaughan and Bell 2009).

Conceptually, an AMU is meant to improve the quality of care given to acute patients and to provide the organisational means for rapid assessment. Stabilised patients can be moved from the ED to an AMU where they are diagnosed and treated before being transferred to a destination ward or discharged. Although all AMUs are different, they share several distinct characteristics. Scott, Vaughan and Bell (2009) defined the concept of an AMU using the following explicit characteristics. First, AMUs are specifically staffed and equipped to receive, from EDs, medical in-patients with acute medical illnesses. Second, the patients receive expedited multidisciplinary and medical specialist assessment, care and treatment for no more than a designated period (typically 24 to 72 hours) before being either discharged or transferred to an appropriate medical ward. Third, the AMUs are supervised by consultants experienced in acute general medicine and feature multidisciplinary teams that comprehensively assess and manage both medical illness and functional disability. Finally, in many instances, the AMUs are geographically co-located with EDs and key diagnostic services such as pathology and radiology.

The specific design of an AMU may depend on the healthcare system of the country in which the hospital is situated, but also on the hospital's initial organisation and objectives. Oddoye et al. (2007) observed that different aims and objectives influenced the size, staffing and structure of the various AMUs implemented. Reid et al. (2016) reviewed 17 studies to examine similarities and variations in the components of AMUs. They reported differences with regard to entry sources (not only from ED but also from the community), admission criteria (which patient groups would be admitted), staffing (which functions were involved in AMU care), operational policies (work patterns) and designated period before transfer.

The AMU concept appears in the academic literature under a variety of names. Scott, Vaughan and Bell (2009) listed the following synonyms: Acute Medical Unit, Acute Medical Assessment Unit, Medical Assessment and Planning Unit, Acute Assessment Unit, Acute Medical Ward, Acute Planning Unit, Rapid Assessment Medical Unit and Early Assessment Medical Unit. Other synonyms mentioned in the literature include Medical Assessment Unit (Oddoye et al. 2009), Acute Medical Admission Unit (Moloney, Bennet and Silke 2007) and Emergency Medicine Ward (Lo et al. 2014). Even though the term 'observation unit' is used in the literature, this is often considered a slightly different concept to an AMU because observation units are generally staffed by ED staff (Cooke, Higgins and Kidd 2003; Zun 1990). The Federation of Medical Royal Colleges recommends using the term Acute Medicine Unit to describe such units (Jayawarna et al. 2010).

2.2 AMU research: impact on performance and methodology adopted

Most studies reporting on the effectiveness of AMUs adopt an observational non-longitudinal design where the outcomes of a historical patient group, prior to an AMU being implemented, are compared to a similar group after an AMU has been established (Reid et al. 2016). In this approach, controlling temporal trends and accounting for other changes made in the design or operation of the hospital system can be challenging. Further, given the heterogeneous AMU designs in these studies, it is difficult to generalise the findings and conclude which AMU components are effective (Reid et al. 2016; Van Galen et al. 2016).

The effects of introducing an AMU on performance may not be the same for every hospital. Without an AMU, some hospitals have dedicated spare capacity (i.e.

extra beds) in each ward to handle the unpredictable arrival of acute patients, while other hospitals pool the available spare capacity across wards. A flexible pool can be used for all acute patients and better absorbs variations in arrivals than the alternative in which a hospital has dedicated beds for acute patients in each ward. Consequently, the benefits of implementing an AMU could well be greater for hospitals that previously had dedicated spare capacity in each ward than for hospitals that used spare capacity flexibly.

The effectiveness of AMUs can be judged from a perspective of patient care quality and/or from a healthcare costs perspective. It is apparent that the general objective of introducing an AMU is to improve patient care *and* to reduce the pressure on beds *but* within existing resources (Moloney et al. 2005). The reported benefits as stated in several review papers (Scott, Vaughan and Bell 2009; Byrne and Silke 2011; Reid et al. 2016) can be grouped in three main types: medical benefits, satisfaction benefits and logistical benefits (see Table 1). Further, these benefits are all related only to acute patients and focus on the ED and/or AMU units of the hospital. The impact of AMUs on other parts of the hospital (wards) or on elective patient flows has been overlooked in existing research. To address this imbalance, this paper focuses on the hospital-wide logistical impact of implementing AMUs.

Table 1: General groupings of AMU benefits

Medical	**Satisfaction**	**Logistical**
Mortality rate	Patient satisfaction	Hospital Length of Stay
Readmission rates	Staff satisfaction	Direct discharge rate
		ED Length of Stay
		ED waiting times

3 AMU design at a Dutch hospital

There are around ninety hospitals in the Netherlands, and these have increasingly been establishing AMUs. By 2010, six had introduced an AMU, by 2012 there were fourteen and by 2014 around eighteen. Our simulation study was part of a feasibility project initiated by the manager of the ED of a large Dutch hospital that was interested in the concept of an AMU. The hospital has around 590 beds and treats 28,000 inpatients and 145,000 outpatients each year. Their ED receives around 24,000 patients annually, of which around 40% need to be admitted. This means that the hospital needs to typically handle around 25-30 acute admissions each day.

One aim of the hospital in implementing an AMU was to separate acute and elective patient flows, so that the care provided could be tuned to the characteristics of each patient group. Whereas acute patients require rapid admission, diagnoses and treatment in a safe environment, elective patients require reliable care without excessive disturbances. The decision-makers expected that an AMU would reduce the waiting times of patients who were to be admitted from the ED, reduce the length of stay (LOS) for acute patients and reduce the number of acute patients admitted to off-service wards (wards other than their intended destination ward). They were aware that the AMU beds were likely to have a lower utilisation rate than existing wards but hoped that an increase in the utilisation of the latter (number of elective patients) would compensate for this. They anticipated this increase in ward utilisation because some of the uncertainty and variation due to acute arrivals would be taken over by the AMU. Further, they expected the work pressure experienced by ward staff to be reduced but also anticipated a need for experienced and highly skilled nurses to assess highly complex cases in the AMU. Within the hospital's feasibility project, our simulation focussed specifically on the logistical impact of the design choices. The decision-makers were very interested to see the effects of decisions taken in terms of hard numbers.

Design choices that were considered in the simulation were the size (#beds) of the AMU, the length of the designated period (maximum stay) and the transfer policy. While acute admissions would generally be admitted to the AMU, there would be exceptions (e.g. paediatrics, gynaecology and oncology). The decision as to which acute patient groups would be admitted through the AMU, and which groups would bypass this, was made in advance and thus fixed in the simulation. Also, the daily pattern within the AMU was discussed and fixed (see Figure 1). In essence, medical specialists would visit their patients in the AMU before 10:00 and then, at 10:00, it would be decided which patients should be transferred to the regular wards. Around 11:00, these patients would be transferred. Depending on the transfer policy determined, there might be another transfer opportunity at 15:00, when additional patients could be transferred to the regular wards. This would require a second round of medical specialist visits sometime before 15:00, and it was assumed that this would quicken the diagnosis.

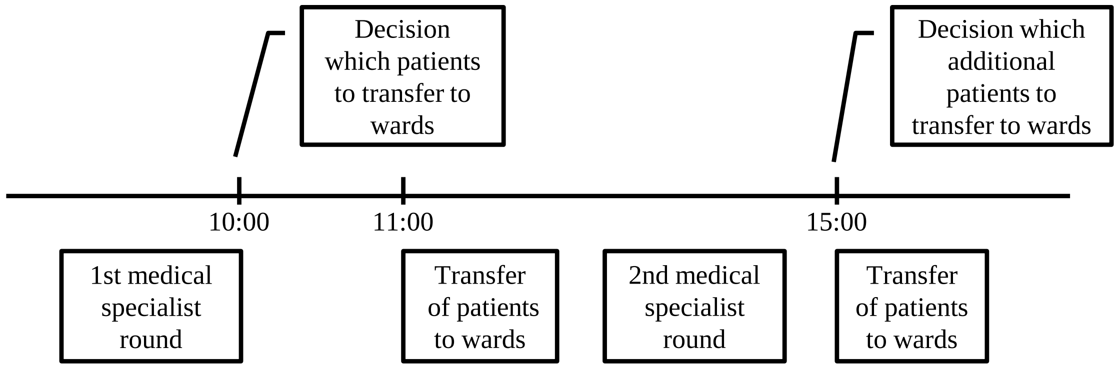

Figure 1: Daily pattern within the proposed AMU.

4 Simulation study

We adopted a Discrete Event Simulation (DES) approach in our study. DES is an appropriate tool for studying the performance effects (such as on patient waiting times) of operations management actions in different healthcare designs (Demir et al. 2015; Lu, Xie and Jiang 2015). DES is particularly appropriate since we have to take account of non-standard and time-dependent variations in, for instance, the arrival of acute admissions, the interconnectedness of the AMU and wards, the complexity of multiple patient types (classes) and the requirement to model a shift of capacity from wards to the AMU. These characteristics make it very hard, if not impossible, to deal with the problem analytically. In our study, the simulation models were established within the Tecnomatix Plant Simulation 10.1.6 object-oriented simulation software package (Siemens Product Lifecycle Management Software II (DE) GmbH).

4.1 Input data

One year of data, excluding the summer vacation period, was used to derive input distributions for the simulation. These data contained the dates and times of patients' arrivals, the patient type (acute, acute outpatient or elective), the specialty (ward) attended and the LOS. Data related to the specialties excluded from the proposed AMU were removed. The data were first categorised based on patient type and, within that, by day of the week and hour of admission. This enabled the creation of time-dependent Poisson arrival distributions for each patient type. Next, we assigned a specialty to each patient using frequency distributions based on historical data. We determined such frequency distributions for all specialties for each day of the week and for each patient type. For elective patients particularly, the likelihood that a specialty is assigned to a certain day of the week varies due to the schedule of the operating rooms. Table 2 shows an example for four specialties. Finally, the LOS distributions were determined by specialty for each patient type.

Table 2: Example frequency table (%) of specialties assigned per day

Specialty	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Cardiology	4.84	20.86	21.82	12.28	21.78	29.9	20.75
Internal medicine	0.69	2.13	3.38	3.27	3.72	2.56	3.77
Otorhinolaryngology	0.86	7.34	5.33	9.06	0.17	8.11	0
Dermatology	0	0.08	0.05	0.13	0	0.15	0
…	…	…	…	…	…	…	…
All specialties	100	100	100	100	100	100	100

4.2 Model Description

The simulation model includes patients, wards and beds. The ED is not directly included in the model, and so the acute patient flow starts with acute admissions. To represent the current situation, without an AMU, the simulation model generates patients (acute admissions and elective patients) and their associated attributes (specialty assigned, LOS) based on historic input distributions relating to patient type, day of the week and time of the day. Depending on patient type and specialty, patients are then allocated to one of the hospital’s nine wards where they occupy a bed for the determined LOS. Of the nine wards, six are non-surgical and three surgical.

Depending on the available bed capacity, the model first tries to assign a patient to the appropriate destination ward (related to their assigned specialty), then possibly to an off-service ward. In this way, the hospital applies a form of limited flexible spare capacity through which bed blocking may be reduced at the cost of having more patients admitted to off-service wards. If there are no beds available anywhere, an acute patient will wait in the ED for admission to their intended destination ward while elective patients are rescheduled.

When an AMU is included in the model, the first step is then to determine whether a patient will enter the AMU or go straight to a ward based on the specialty assigned. If the patient is to be admitted to the AMU, they will be assigned a bed if one is available or, if not, they will wait in the ED until a bed is found in the AMU. While patients may enter the AMU at any time of the day or night, they can only leave it at one or two predetermined and fixed transfer moments (as discussed earlier – see Figure 1). In the simulation, all patients are discharged after their expected LOS.

4.3 Experimental Factors

The research was conducted in two phases. In the first phase, we focussed on the design of the AMU in order to create an AMU that could deal with the variability in the incoming stream of acute patients in our case hospital. Here, we considered combinations of AMU size, designated period and transfer policy. In the second phase, the focus was on the hospital-wide effects on performance of implementing an AMU. Here, we investigated whether elective patient flows and acute patient flows that still made use of the wards would be affected by the implementation of an AMU. In this, we considered the current situation (without an AMU) and contrasted this with several AMU designs that were determined in the first phase as promising.

4.3.1 Experimental Factors in the Design of the AMU

Three experimental factors are considered in the design of the AMU: (1) the length of the designated period, (2) the size of the AMU and (3) the transfer policy. For the length of the designated period, we considered two options: 24 hours (one night) and a period of 48 hours (two nights). These options were chosen based on the fact that most hospitals that have implemented an AMU have chosen one of these periods (Cooke, Higgins and Kidd 2003). Furthermore, the designated period must be long enough to enable at least an initial diagnosis but should not be too long because this might decrease patient satisfaction. Several hospital representatives mentioned that a longer designated period is more onerous for patients because the AMUs usually are more hectic/turbulent than the wards. Note that we consider a patient to have stayed a night if they were present at midnight. In other words, a patient arriving at 23:00 has stayed one night in the AMU when they are checked at 10:00 the next morning, whereas a patient arriving at 01:00 has not yet stayed a night.

Clearly, in terms of AMU size, the longer the designated period, the more beds that will be required to accommodate the acute patient flow. We varied the number of beds within the AMU from 20 to 50, in two-bed increments, when the designated period was set at one night, and between 30 and 70 when the period was set at two nights. We selected these ranges based on a few preliminary simulation test results. Another effect of a longer designated period is that the direct discharge rate will be higher: more patients will be discharged within the designated period and thus fewer patients will need to be transferred from the AMU to a ward.

We developed two alternative transfer policies. In the first, the only consideration is how long the patient has already spent in the AMU. If, at the decision moment (10:00), the patient has already spent the maximum number of nights in the AMU (one or two, depending on the designated period set), they will be transferred to a ward at 11:00 unless the expectation is that they can be discharged before midnight of the current day. These patients do not need to be transferred to a ward because they will be discharged from the AMU within the designated period. The second transfer policy similarly considers the patient’s LOS in the AMU, but includes an additional transfer opportunity at 15:00. At this second transfer moment, the number of beds available in the AMU is checked against a predefined number of free beds. If there are insufficient free beds, the patients who have spent longest in the AMU will be transferred to a ward until the number of available beds equals the predefined target, or until there are no patients left who arrived at the AMU before 10:00. Such a policy may reduce the number of beds required in an AMU since it forces patients to be transferred to a ward when insufficient beds remain available at the second transfer moment. Even though this is positive from a capacity point of view, it may impact on the quality of patient care since it may move patients from the AMU earlier than would otherwise be the case. One could consider other transfer policies, for example, there could be a process to proactively request a patient be transferred when a bed becomes available in the desired destination ward. This could be beneficial when the AMU is highly occupied. However, this could result in the transfer of patients whose diagnostics are not finalised, and this could easily lead to a delay in diagnostics.

To represent the first transfer policy, we set the number of free beds at 0; and, for the second, varied this number between 5 and 20 (1 night designated period) or 5 and 25 (2 nights) (in five-bed increments). These maximum values were determined through preliminary test results. Since the minimum size of the AMU with a designated period of one night is 20 beds, the upper limit for the number of free beds equals 20 in this setting.

4.3.2 Factors in Examining the Effects of an AMU on the Wards

In simulating what appears, from the first phase, to be a good AMU design, we subtract the number of beds needed for the specific AMU design from the wards. The question is whether removing this number of beds from the wards has any negatives for other patient flows. We included a reduction in the LOS as a variable in our simulations, and experimented with decreasing the historic LOS data. This is to determine whether the reduction in LOS that is anticipated as a consequence of adopting an AMU is an additional advantage or a necessity if one is to implement an AMU without having a detrimental effect on certain patient flows without an overall increase in the number of beds.

The two experimental factors we applied in determining the effects of an AMU on the wards are: (1) the specific AMU design (no AMU versus three alternative AMU designs resulting from the first phase) and (2) a reduction in the LOS of acute patients.

4.4 Performance Indicators

The performance indicators we investigated are summarised in Figure 2. First, the numbers of acute patients waiting to be admitted to the AMU (situation 1) or to the wards (2) should be minimised. Positive percentages indicate that acute patients are waiting in the ED because of a lack of beds in the AMU (1) or for an available bed in their destination ward (2). The mean and standard deviation of waiting times of acute patients waiting in the ED to be admitted to the AMU (3) are recorded as well. With these performance indicators (1,3) the influence on ED operations can be shown. Similarly, a positive percentage of elective patients that need to be rescheduled (4) due to the unavailability of beds in their destination ward or in an off-service ward is undesirable The occurrence of any of these events will have a negative impact on the quality of patient care. In practice, this will probably be avoided by using additional resource flexibility. However, because our simulation has fixed resource capacities, queues may occasionally build up. In the initial simulation, without an AMU, this rarely happens with only around 1.09% of the acute patients waiting for a place in a ward with waiting times (M = 6.19, SD = 6.45 hours), and only 1.25% of elective patients having to be rescheduled. This scenario provides the baseline against which we compare the three selected AMU designs in the second phase of our experiments.

In our simulation with an AMU, the percentages of acute patients who are discharged directly from the AMU (5 - the direct discharge rate) are recorded. Also, the average number of acute patients admitted during each night (between 18:00 and 07:00) (6) is recorded so as to be able to show the extent of nightly disturbances caused by acute admissions when there is no AMU.

In the simulations, for both acute patients and elective patients, the percentage admitted to off-service wards (7) is calculated. The AMU's utilisation rate (8) is the last piece of data retained.

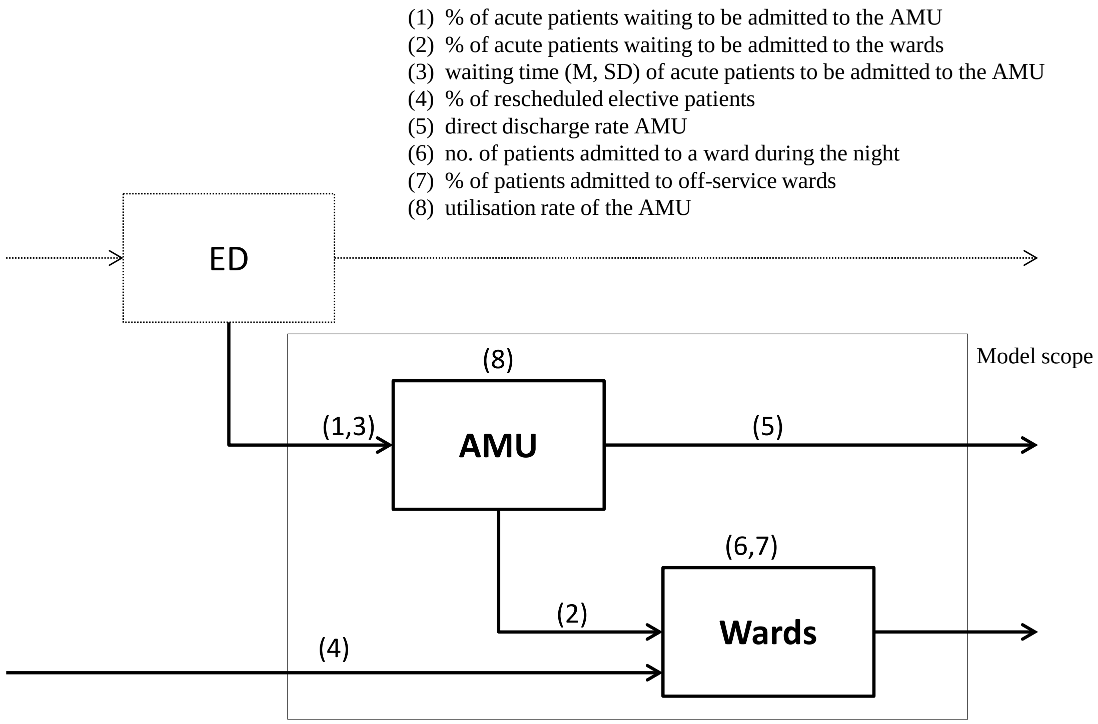

Figure 2: Operationalised performance measures.

4.5 Model verification and validation

In order to verify the model and ensure that it was built correctly, we compared it with a conceptual model that we prepared in cooperation with the hospital. Such a conceptual model is "a non-software specific description of the computer simulation model, describing the objectives, inputs, outputs, content, assumptions and simplifications of the model" (Robinson 2014: p.77). The created code was checked by a person other than the programmer, the model's output was examined for reasonableness under a broad range of settings, and the debugger, event list and the software's animation functions were used to verify the correctness of the model. Model validation entailed data validation, operational validation and experimentation validation. Input data were provided by the hospital and checked for adequateness by the authors. The outputs of the model without an AMU were compared with the real outputs of the hospital, and hospital representatives were asked whether the model and its behaviour appeared reasonable (face validity: Sargent 2013) during a structured walkthrough of the model presented by the researchers at a project meeting.

With respect to experimentation validation, we used the replication/deletion approach (Law 2007) to estimate the steady-state means of the output parameters. Here, Welch's procedure (Law 2007) was applied to gain an initial indication of the required warm-up period, and we increased this somewhat to be on the safe side. In setting the run length, we used a rule of thumb that it should be at least ten times the warm-up period (Robinson 2014). Based on the confidence interval method, we determined that the number of replications per experiment should be 30, with a warm-up period of 21 days and a total length of 300 days (in an hour-by-hour simulation). Different seeds were used in each replication to maximise sampling independence.

5 Results

5.1 AMU Design

We determined the appropriate size of the AMU for the Dutch hospital for each designated period by setting a maximum on the percentage waiting for admission to the AMU. Figure 3 shows the interaction effect, between the size of the AMU (in number of beds) (x-axis) and the number of free beds, on the percentage waiting for the AMU when the designated period is one night. Note that the '0 beds free' series represents the first transfer policy, which is based solely on a patient's LOS in the AMU. The '5-20 beds free' series represent the second transfer policy, which includes a second transfer opportunity at 15:00 and ensures that the number of available beds is at least equal to a predefined number of free beds. The results indicate that around 42 beds are required to keep the percentage waiting for the AMU to around 0.5%. Whilst ideally nobody should be waiting for the AMU, waiting cannot be completely avoided in a simulation with stochastic input data and fixed AMU resources, and so we set a threshold at around 0.5%. Without an AMU 1.09 % of acute patients need to wait for a ward (and thus use up ED capacity). As such, we thus positively influenced ED operations by designing an AMU of such a size that the percentage of acute patients waiting to be admitted to the AMU decreases to around 0.5%.

The choice of transfer policy does not have much influence, especially when the AMU has 42 or more beds. With that number of beds, there are always sufficient beds available at the second transfer moment to absorb the probable number of remaining patient arrivals on any day. Thus, having chosen a designated period of one night, an AMU design labelled '1/42/0', denoting the number of designated nights (1), the number of beds (42) and the predefined number of free beds (0), would thus be appropriate.

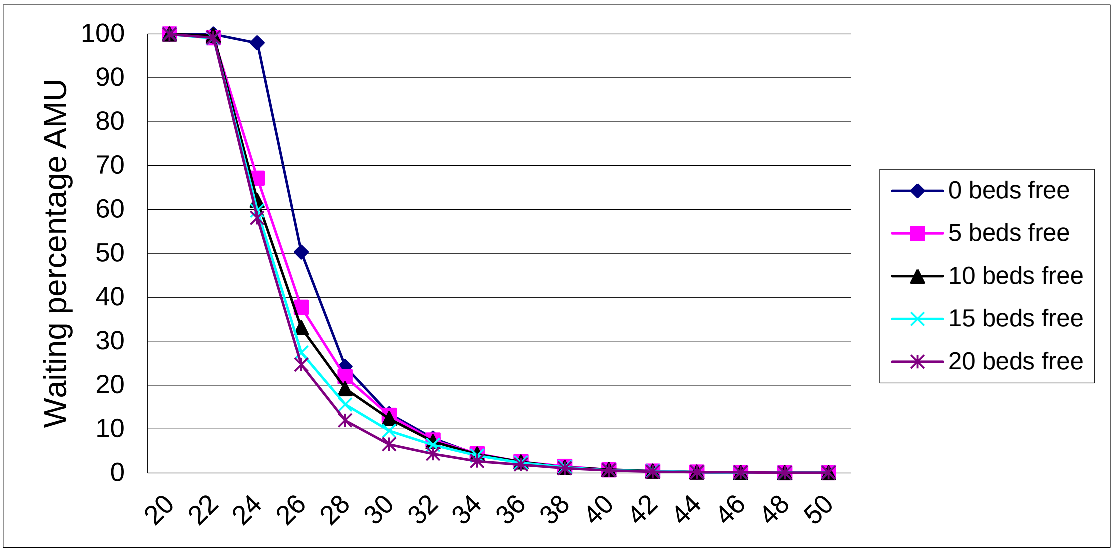

Figure 3: Interaction effect between the size of the AMU (#beds) and the transfer policy on the percentage waiting for the AMU with a designated period of one night.

Having opted for the 1/42/0 AMU design, the model then calculates the direct discharge rate as 24.2%. After being assigned a bed in ‘this’ AMU, acute patients spend 18.7 hours on average in the AMU and its bed utilisation rate equals 49.8%. On average 0.3% of the acute patients waited for admission to the AMU with waiting times (M = 3.7, SD = 2.95 hours).

Figure 4 shows that the transfer policy has a greater influence when the designated period is set at two nights. Without a second transfer opportunity (to be utilised when there is deemed insufficient free beds in the AMU), the AMU needs to contain at least 66 beds to achieve a waiting percentage for the AMU of no more than 0.5%. This ‘2/66/0’ AMU design would then be appropriate for meeting the ambitions. With a smaller AMU, the waiting percentage can only be kept at around 0.5% by establishing a second transfer moment at which a certain number of beds are freed up. The model shows that a 54-bed AMU with a process to ensure 25 free beds at the second transfer moment (i.e. a ‘2/54/25’ design) would work.

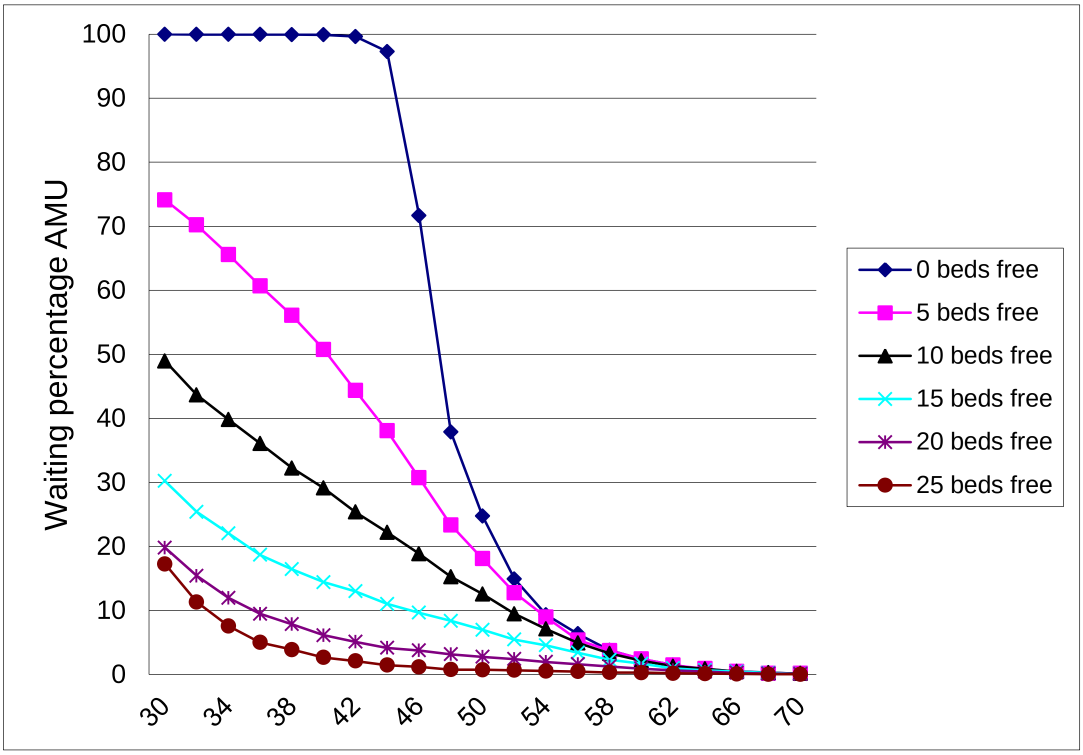

Figure 4: Interaction effect between the size of the AMU (#beds) and the transfer policy on the percentage waiting for the AMU (designated period = two nights).

With the 2/66/0 AMU design, the direct discharge rate becomes 34.3%. Acute patients spend an average of 37.1 hours in the AMU with a bed utilisation rate of 63.6%. On average 0.5% of the acute patients waited for admission to the AMU with waiting times (M = 4.79, SD = 3.58 hours). In comparison, with the 2/54/25 AMU design, the direct discharge rate is 31.6%, acute patients spend an average 32.7 hours in the AMU, the bed utilisation rate is 68.3%, and 0.58% of the acute patients waited for admission with waiting times (M = 3.63, SD = 2.88 hours).

These results show that the variability in acute patient arrivals is easier to absorb with a longer designated period, resulting in a higher average bed utilisation rate in the AMU with similar low percentages of patients waiting for the AMU and similar waiting times. Although the number of beds in the AMU can be reduced by using a second transfer moment when the designated period is two nights, this does mean that some patients have to be transferred to a ward much earlier than would otherwise be the case.

One consequence of this is a drop in the direct discharge rate and another that acute patients spend less time on average in a 2/54/25 AMU design than in a 2/66/0 AMU design.

5.2 Effects of implementing an AMU on Wards

In the simulated design without an AMU, on average 19,205 patients were treated in a 300-day period, of which 11,016 were elective patients (57.4%) and 8189 acute admissions (42.6%). The percentage of acute admissions waiting for a ward was 1.1% on average. 94.1% of the acute patients were admitted to their destination ward, meaning that 5.9% were admitted to an off-service ward. On average, there were 11.2 acute admissions each night. Of the elective patients, only 1.3% had to be rescheduled. Of the admitted elective patients, 5% were admitted to an off-service ward.

In order to show the effects on the wards of creating an AMU, we next simulated the three potential AMU designs established in the first stage (1/42/0; 2/66/0; 2/54/25). As already noted, hospital managements usually redesignate bed capacity when implementing an AMU. To simulate this, we subtracted the number of beds in each AMU design from the total in the various wards. To determine how many beds to remove from each ward within each design, we tried two approaches. The first approach (A1) simply removes beds from all the wards in proportion to the original number of beds. The second approach (A2) considers the share of acute patients that a ward would typically admit and removes beds in proportion to that share. Table 3 shows the resulting number of beds per ward for all three designs using these two approaches.

Table 3: Number of beds per ward (N = non-surgical, S = surgical) for basic non-AMU situation and for the three AMU designs using the first (A1) and second (A2) approaches.

		AMU	N1	N2	N3	N4	N5	N6	S1	S2	S3
no AMU		0	33	33	20	58	81	16	34	92	23
42/1/0	A1	42	29	30	18	52	72	14	30	82	21
	A2	42	28	28	19	48	72	15	32	84	22
54/2/25	A1	54	28	29	17	50	70	14	29	79	20
	A2	54	27	26	18	45	70	15	32	82	21
66/2/0	A1	66	27	28	17	48	67	13	28	77	19
	A2	66	25	24	18	42	68	15	31	80	21

Table 4 shows the resulting performance of the overall hospital with these three AMU designs when the numbers of beds in the wards are reduced in line with the two approaches (see Table 3). These results show that the percentage of acute patients waiting and the percentage of elective patients rescheduled are markedly increased compared to the situation without an AMU. This means that there are more acute patients having to wait before they can be moved to an appropriate ward, and more elective patients having to be rescheduled (because they cannot be placed in their destination ward or any of the off-service wards).

Table 4: Performance of three alternative AMU configurations with bed reductions in line with approaches A1 and A2. Results shown in terms of % difference to a situation without an AMU.

	No AMU		A1	% difference	A2	% difference
Percentage of acute patients waiting for AMU and/or ward	1.09	42/1/0	3.56	227.53	4.97	356.84
		54/2/25	3.69	239.76	4.73	334.73
		66/2/0	3.45	217.06	5.80	433.56
Percentage of elective patients rescheduled	1.25	42/1/0	4.16	232.80	4.29	243.07
		54/2/25	2.73	118.56	2.77	121.65
		66/2/0	4.24	238.92	4.43	253.94
Percentage of acute patients admitted to off-service ward	5.85	42/1/0	6.81	16.50	8.23	40.68
		54/2/25	5.67	-2.99	7.44	27.28
		66/2/0	5.90	0.95	8.19	39.99
% elective patients admitted to off-service ward	5.01	42/1/0	7.79	55.56	7.90	57.78
		54/2/25	7.11	42.02	7.25	44.74
		66/2/0	8.36	66.86	8.52	69.99

Thus, even though the overall resource capacity remains the same, there is a marked decrease in performance that can be explained by the different uses of the transferred resources. The AMU capacity can only be used for acute patients whereas the capacity in the wards can be used for elective and acute patient flows. The results also show that, perhaps surprisingly, the second approach to removing beds from wards generally results in worse performance than the first approach. Therefore, we will continue the analysis using only the first approach.

Since admitting acute patients through an AMU is expected to result in an overall decrease in the time such patients are expected to remain in hospital, we experimented by simulating reductions in the LOS of acute patients. This reduction in LOS, as a consequence of establishing an AMU, will impact on the hospital-wide performance. Consequently, we can see how much the average LOS would need to be reduced to obtain a similar or better overall performance than achieved without an AMU.

Table 5 shows the relevant performances in the situation without an AMU (first row) and for each of the three selected AMU designs with reductions in the LOS of acute patients varying from zero to 16%. We stopped at 16% because this was sufficient to overcome all the negative effects. The shaded cells show the percentage of LOS reduction required for each performance measure to at least equal that in the non-AMU situation.

Table 5: Performance without an AMU (first row) and for each of the three selected AMU designs (with a reduction in the LOS of acute patients varying from 0 to 16%)

	% Acute patients waiting for AMU and/or ward			% Elective patients rescheduled			% Acute patients admitted to off-service ward			% Elective patients admitted to off-service ward		
no AMU	1.09			1.25			5.85			5.01		
AMU design	42/1/0	54/2/25	66/2/0	42/1/0	54/2/25	66/2/0	42/1/0	54/2/25	66/2/0	42/1/0	54/2/25	66/2/0
LOS unchanged	3.56	3.69	3.45	4.16	2.73	4.24	6.81	5.67	5.90	7.79	7.11	8.36
LOS - 1%	3.38	2.81	2.84	3.87	2.57	4.09	6.92	5.66	5.92	7.65	6.99	8.34
LOS - 2%	2.56	2.56	2.16	3.36	2.28	3.50	6.27	5.51	5.63	7.14	6.70	7.83
LOS - 3%	2.34	2.40	1.95	3.20	2.21	3.27	6.17	5.13	5.45	7.12	6.33	7.65
LOS - 4%	2.17	2.30	1.93	3.05	2.08	3.14	6.11	4.97	5.06	6.84	6.14	7.48
LOS - 5%	2.05	1.95	1.60	3.07	1.67	2.84	5.68	4.78	4.84	6.55	5.86	7.12
LOS - 6%	1.66	2.15	1.58	2.60	1.77	2.92	5.46	4.86	4.51	6.37	5.92	7.06
LOS - 7%	1.51	1.98	1.19	2.34	1.71	2.31	5.25	4.58	4.26	6.15	5.58	6.36
LOS - 8%	1.34	1.77	1.26	2.22	1.42	2.23	5.08	4.30	4.19	6.06	5.33	6.40
LOS - 9%	1.32	1.50	1.38	2.07	1.29	2.45	4.80	4.12	4.16	5.85	5.17	6.45
LOS - 10%	1.27	1.62	1.21	2.02	1.25	2.19	4.73	3.81	3.95	5.67	4.91	6.11
LOS - 11%	1.13	1.29	1.13	1.87	1.08	2.08	4.56	3.45	3.83	5.47	4.63	6.02
LOS - 12%	1.06	1.36	0.84	1.57	0.98	1.75	4.32	3.44	3.50	5.24	4.51	5.84
LOS - 13%	0.91	1.17	0.82	1.41	0.90	1.51	3.87	3.29	3.26	4.89	4.14	5.38
LOS - 14%	0.82	1.04	0.92	1.33	0.79	1.60	3.67	3.07	3.18	4.54	3.89	5.34
LOS - 15%	0.75	0.94	0.81	1.20	0.74	1.36	3.56	2.84	3.25	4.48	3.98	5.13
LOS - 16%	0.67	0.89	0.69	1.05	0.75	1.22	3.32	2.67	2.72	4.15	3.77	4.84

The results show that, for all three AMU designs, the LOS reduction must be substantial (more than 10%) to achieve a similar performance to that in the situation without an AMU for the percentage of acute patients waiting, the percentage of elective patients needing to be rescheduled and the percentage of elective patients having to be admitted to off-service wards. However, only a 5% reduction in LOS is required to avoid an increase in the number of acute patients failing to get a bed in the destination ward. This lower figure results from the fact that, unlike elective patients, acute patients are not rescheduled when they cannot be admitted, but instead 'wait' at their destination ward. While this increases the percentage of acute patients waiting, it does not influence our performance indicator of the percentage of acute patients admitted to an off-service ward.

6 Discussion

As mentioned in the literature review section, previous research has shown the medical benefits, satisfaction benefits and logistical benefits of implementing an AMU considering acute patients only (Bennet and Silke 2007; Byrne and Silke 2011; Jayawarna et al. 2010; Moloney et al. 2005; Moloney,; Reid et al. 2016; Rooney et al. 2008; Scott, Vaughan and Bell 2009). This research has shed light on the hospital-wide logistical impact of implementing an AMU.

By designing an AMU of sufficient size, we reduced the waiting percentages for acute admissions from 1.1% to around 0.5%. This slightly increased the availability of ED capacity, which in turn will improve ED operations. This result is in line with the (limited) evidence that suggests that implementing an AMU may improve ED LOS and ED waiting time (Moloney et al. 2005; Reid et al. 2016). Moloney et al. (2005) showed that ED waiting times for a hospital bed significantly shortened following the introduction of an AMU in an Irish hospital, with a reduction of the number of patients waiting in the ED for a hospital bed of 30%. However, we also show that if an AMU is established by reallocating beds formerly in the wards to the AMU, a substantial reduction in the time acute patients stay in hospital is required to compensate for the negative logistical consequences. This broader impact of an AMU implementation had not been studied before.

The main finding from our study is that implementing an AMU affects the logistical performance of both acute *and elective* patient flows in a hospital. For the three AMU designs (42/1/0, 54/2/25 and 66/2/0), the negative impact on the percentage of elective patients that need to be rescheduled, the percentage of elective patients admitted to off-service wards, and the combined percentage of acute patients waiting for the AMU and/or ward, is not that dissimilar. Even though the variability in acute patient arrivals can be better absorbed with a longer designated period (resulting in a higher utilisation rate of AMU beds), more beds need to be transferred from the wards and this leads to similar reductions in LOS being required to compensate. With a relatively short designated period (the 42/1/0 design), more acute patients need to be transferred to a ward from the AMU since the direct discharge rate is lower and there seems to be insufficient time to introduce more sophisticated transfer policies. The direct discharge rates in our model show the percentage of acute admissions to the AMU that are sent home within the designated period. These patients do not need to be transferred to a ward and thus do not disturb the elective patient flows.

Based on these results, a designated period of two nights seems preferable over a single night. The relevant literature shows that designated periods are typically between 24 and 74 hours (Van Galen et al. 2016; Reid et al. 2016) but does not offer recommendations for an ideal length. It would be valuable if further research were to study empirically the relationship between the length of the designated period and the reduction in the length of hospital stays.

Based on most yardsticks, the 54/2/25 design seems to require a smaller LOS reduction than the 66/2/0 design to compensate for the performance losses associated with introducing an AMU with the notable exception of the percentage of acute patients waiting for an AMU and/or ward bed. The second transfer opportunity that is included in the 54/2/25 design means that patients can be transferred to a ward even if not enough beds are available, and thus fewer beds are required in the AMU compared with the 66/2/0 design where there was no second transfer option. In our model, the smaller AMU leaves more beds in the wards. However, in practice, this second transfer opportunity means that some patients leave the AMU earlier than might be ideal (in order to free up beds) and the impact of this on the quality of patient care should be assessed when evaluating any trade-off.

Previous studies have reported on the effectiveness of AMUs in terms of LOS reduction (see e.g. Downing, Scott and Kelly 2008; Moloney, Bennet and Silke 2007). The arguments why AMUs lead to shorter stays include that diagnosis and first treatment can be expedited because the way an AMU is organised enables quick access to medical staff and equipment such as CT and MRI scanners (Cooke, Higgins and Kidd 2003). Further, by having an AMU, an extra decision moment regarding patient discharge is built into the process: at the end of the designated period, a decision has to be made whether to discharge a patient or admit them to a ward. In practice, several patients are discharged after the designated period who, if they had gone straight to a ward, would not have been discharged so soon. This contributes to a lower average LOS for acute patients. Thus, there are several effects that may compensate for the deterioration in performance resulting from the more specific use of resources when an

AMU is introduced. In our study, we did not consider the hospital LOS as a dependent variable, but we included it as an independent variable to investigate the required reduction to compensate for the performance deterioration. We showed that the average acute patient LOS needs to be reduced by more than 10%. Previous studies report actual LOS reductions of 16% (Downing, Scott and Kelly 2008), 20% (Lo et al. 2014), 14-20% (Moloney et al. 2005) 29% (Moloney, Bennet and Silke 2007), and 16-36% (Scott, Vaughan and Bell 2009). This would suggest that the negative logistical effects could be compensated.

The Dutch hospital involved in our research concluded that implementing an AMU would not benefit them as much as they had hoped. They expected greater benefits, in terms of bed savings, from introducing an AMU than our results suggested, and therefore the hospital management decided to put the proposed implementation on hold. Recently, they have started to explore the concept again.

7 Conclusions

Conceptually, an AMU is intended to improve the quality of care given to *acute* medical patients and is often associated with a reduced average length of stay (LOS) in the hospital. Previous empirical research has shown that AMUs do improve some aspects, but little attention has been given to the possible negative effect on *elective* patient flows. Our research provides insights into the hospital-wide effects of implementing various AMU designs in terms of both acute and elective patient flows. The complex situation of acute and elective patient flows in a Dutch hospital has been realistically modelled and simulated for a range of AMU designs.

Three design choices were considered in our simulation: the size of the AMU, the length of the designated period, and the transfer policy. The variability in acute patient arrivals can be better absorbed when there is a longer designated period, implying that two nights is preferable to one. Even though this requires a larger AMU (i.e. more beds) than for a designated period of a single night to achieve similar patient waiting percentages and waiting times, the beds will be better utilised and the direct discharge rate will be higher.

In all the AMU designs simulated, shifting existing capacity from wards to an AMU decreased the overall performance in terms of the percentage of acute patients waiting for admission, the percentage of elective patients needing to be rescheduled and the percentage of elective patients admitted to an off-service ward. For these negative effects to be overcome, the average acute patient LOS needs to be substantially reduced (by more than 10%). Overall, the 54/2/25 design seems to require a smaller LOS reduction than the 66/2/0 design to compensate for the performance losses. However, the impact on the 54/2/25 design on the quality of patient care needs to be considered since the 54/2/25 design requires some patients to leave the AMU earlier than they would in the 66/2/0 design. To conclude, achieving a reduction in the LOS of acute patients would appear to be a necessity, rather than an additional advantage, if an AMU implementation that does not involve additional beds is to be considered a success.

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